Fabian Laudenbach[1], Michael Hentschel[1], Moritz Kleinert[2], Hauke Conradi[2], Hannes Hübel[1]
1 AIT Austrian Institute of Technology GmbH, Center for Digital Safety & Security, Information Management, Giefinggasse 4, 1210 Vienna, Austria.
2 Fraunhofer Heinrich-Hertz-Institut, Photonics Components Department, Einsteinufer 37, 10587 Berlin, Germany.
fabian.laudenbach@ait.ac.at
hauke.conradi@hhi.fraunhofer.de

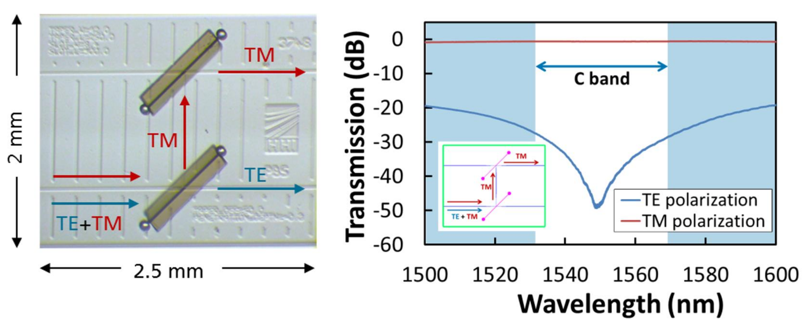
INTRINSIC ENTANGLEMENT GENERATION ON POLYMER-BASED INTEGRATED CIRCUIT

INTRODUCTION

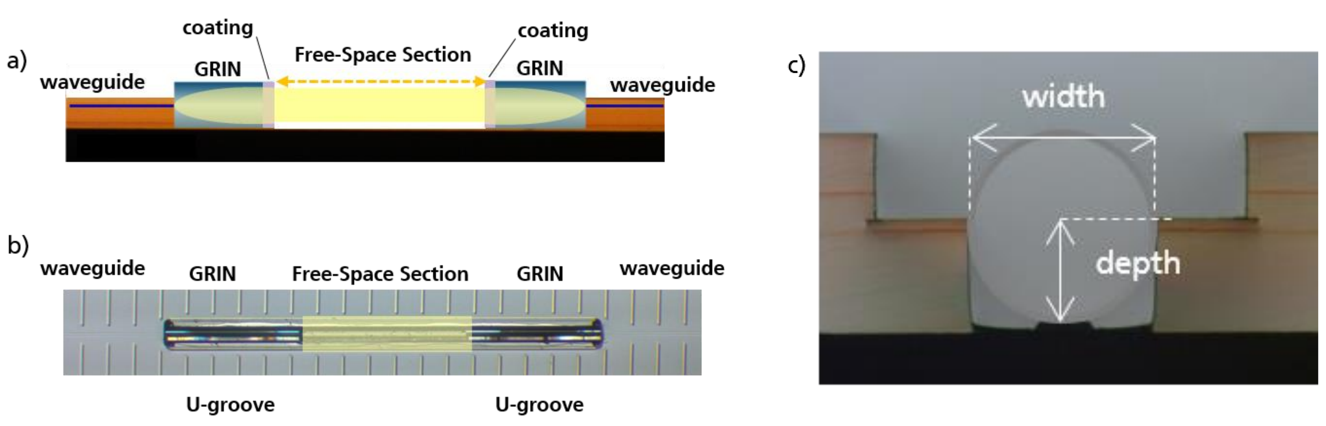
We present a novel way to generate polarisation-entangled photon pairs which is both, highly efficient and simplistic in its experimental implementation. Consisting only of a single unidirectionally pumped nonlinear crystal, our source is predestined for miniaturisation and photonic integration, as we show by presenting a polymer-based integration methodology of this source.

POLYMER-BASED PHOTONIC HYBRID INTEGRATION PLATFORM POLYBOARD

- *Single-mode waveguides optically **transparent from 450 nm to 1650 nm** with low birefringence*
- *Thin-film elements for temp.-insensitive polarization and wavelength routing (e.g. **dichroic mirrors, polarization beam splitters, half-wave plates**)*
- ***On-chip free-space sections** with collimated beams created by GRIN lenses for insertion of bulk optical components like magneto-optic or nonlinear-optic crystals*

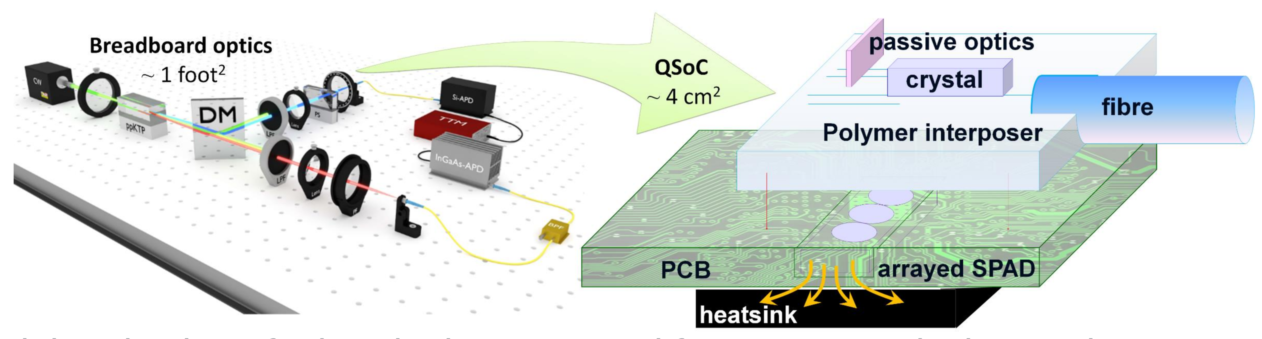


Integrated polarizing beam splitter with 0.7 dB total loss and 50 dB extinction ratio.

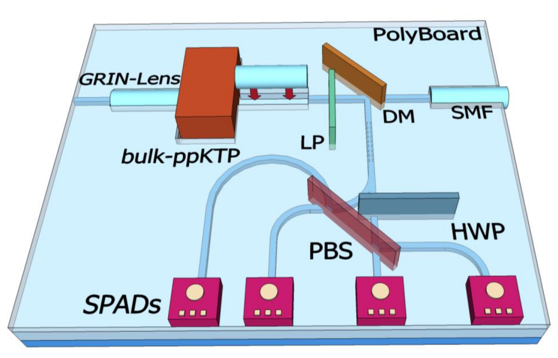


Schematic (a) and top view of fabricated on-chip free space section (b). Cross section of etched U-groove with indicated GRIN lens position (c).

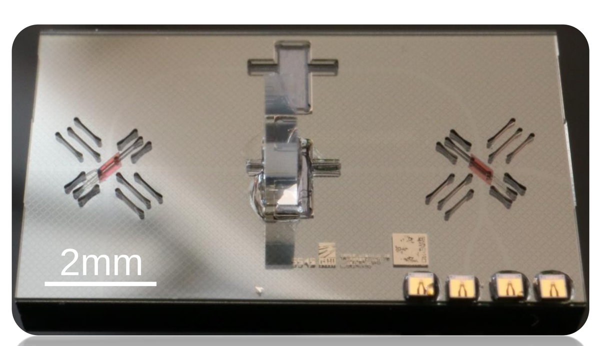
MICRO-OPTICAL BENCH FOR QUANTUM TECHNOLOGY – THE UNIQORN APPROACH



Miniaturization of already demonstrated free-space optical setup by on-chip integration of ppKTP crystal on the PolyBoard platform, via a pair of GRIN lenses.



Schematic of integrated SPDC-source with on-chip BB84-protocol detection.



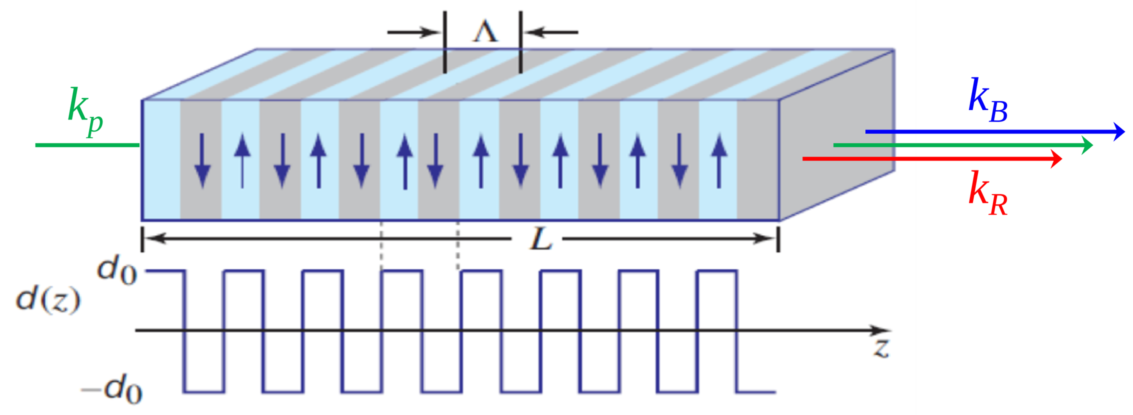
On-chip integration of GRIN-lens-integrated nonlinear optical crystal.

FURTHER READING

- F. Laudenbach, S. Kalista, M. Hentschel, P. Walther, H. Hübel, *A novel single-crystal & single-pass source for polarisation- and colour-entangled photon pairs*, Sci. Rep. **7**, 7235 (2017).
- F. Laudenbach, R.-B. Jin, C. Greganti, M. Hentschel, P. Walther, H. Hübel, *Numerical Investigation of Photon-Pair Generation in Periodically Poled* MTiOXO$_4$ *(M=K, Rb, Cs; X=P, As)*, Phys. Rev. Appl. **8**, 24035 (2017).
- M. Kleinert, D. de Felipe, C. Zawadzki, W. Brinker, J. H. Choi, P. Reinke, M. Happach, S. Nellen, M. Möhrle, H.G. Bach, N. Keil, M. Schell, *Photonic integrated devices and functions on hybrid polymer platform*., Physics and Simulation of Optoelectronic Devices XXV. Vol. 10098. International Society for Optics and Photonics, 2017
- H. Conradi, D. de Felipe, M. Kleinert, M. Nuck, C. Zawadzki, A. Scheu, N. Keil, M. Schell, *High Isolation Optical Isolator: A new Building Block for PolyBoard Photonic Integrated Circuits*, 2018 European Conference on Optical Communication (ECOC). IEEE, 2018.

QUASI-PHASE-MATCHING & COLLINEAR DOUBLE-DOWNCONVERSION

PHASE-MATCHING BY PERIODIC POLING



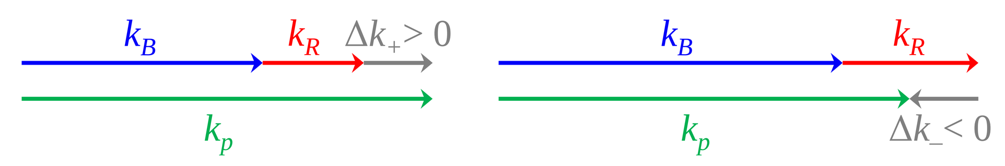
QPM condition:

$$\Lambda = \frac{2\pi}{|\Delta k|}$$

with $\Delta k = k_p - k_B - k_R$

Quasi-phase-matching (QPM) is a method to ensure constructive interference of SPDC-generated radiation by periodic alternation of the nonlinear coefficient d. (Figure from Saleh, Teich, "Fundamentals of photonics," John Wiley & Sons, 2007).

COLLINEAR DOUBLE-DOWNCONVERSION

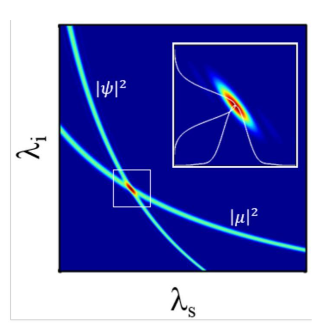


$$\Lambda = +\frac{2\pi}{\Delta k_+} = -\frac{2\pi}{\Delta k_-}$$

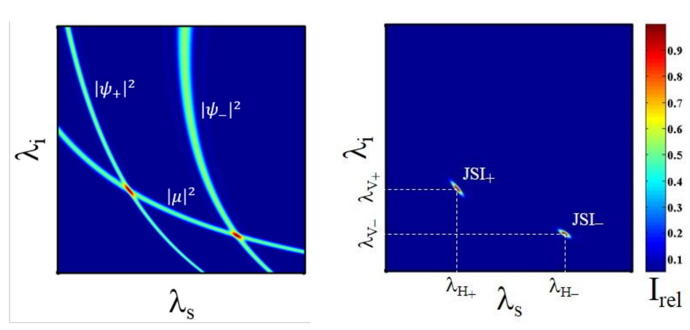
The phase-mismatch vector $\Delta k = k_p - k_B - k_R$ can be positive or negative.

*One periodically poled crystal with periodicity Λ can provide phase-matching for **two** SPDC processes simultaneously if $|\Delta k_+| = |\Delta k_-|$.*

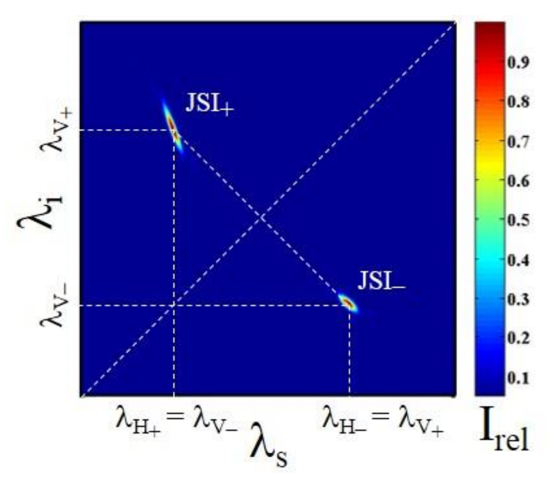
INTRINSIC ENTANGLEMENT



Downconversion occurs where the QPM amplitude $|\psi|$ and the pump laser amplitude $|\mu|$ overlap.



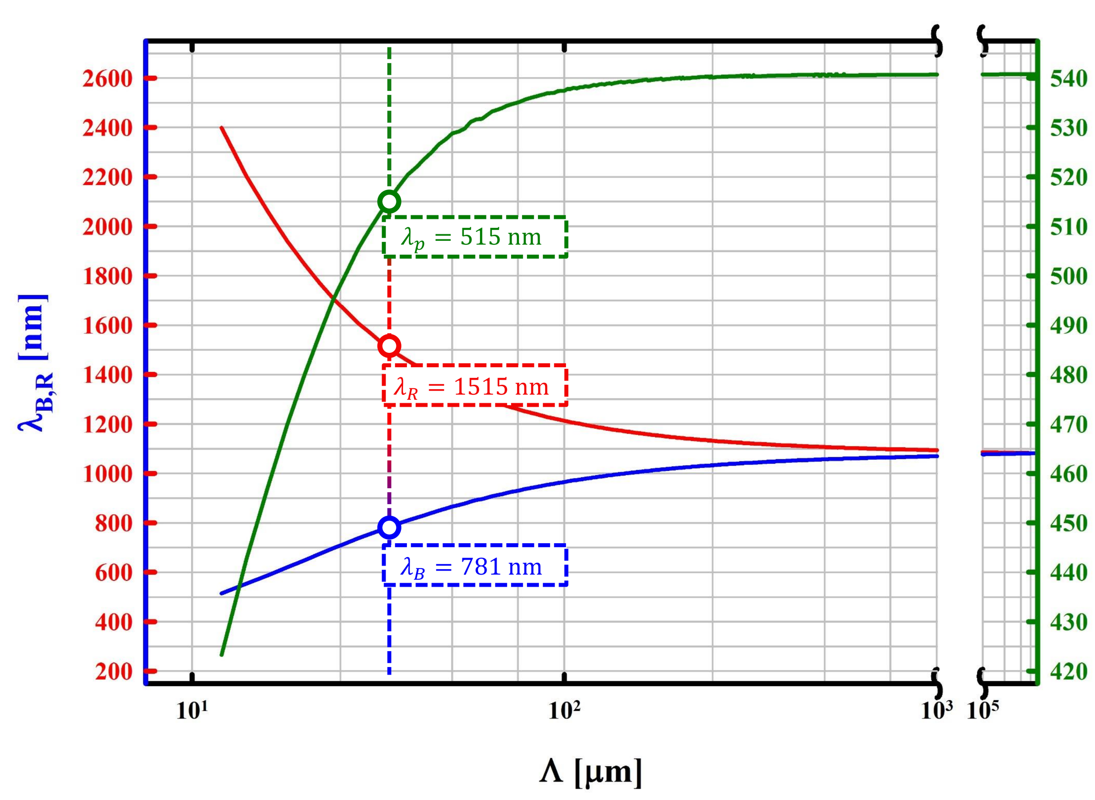
*When **two** QPM amplitudes, $|\psi_+|$ and $|\psi_-|$ (one for Δk_+ and one for Δk_-), overlap with $|\mu|$, **two** SPDC processes are enabled, with joint-spectral-intensity distributions JSI_+ and JSI_- → **collinear double-downconversion.***



*By careful design, the two SPDC processes can be arranged such that they generate photon pairs of the **same wavelength** but **orthogonal polarisation**.*

$$|\Psi\rangle = \left(\alpha \hat{a}^{\dagger}_{H,\lambda_B} \hat{a}^{\dagger}_{V,\lambda_R} + \beta \hat{a}^{\dagger}_{V,\lambda_B} \hat{a}^{\dagger}_{H,\lambda_R}\right) |0,0\rangle$$
$$= (\alpha |H_B V_R\rangle + \beta |V_B H_R\rangle)$$

POSSIBLE IMPLEMENTATIONS



Poling periods and wavelength configurations allowing for intrinsic-entanglement generation in ppKTP. The configuration implemented on our PolyBoard is highlighted by the dashed line and boxes.

ACKNOWLEDGEMENTS

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